Institution of Electrical Engineers.

Extending the Limits of Power Transmission.

AS APPLIED BOTH TO LONG-DISTANCE TRANSMISSION OF POWER AND TO POWER COMPANIES' AREAS.

BY

A. M. TAYLOR, Member.

(*Paper received from the* BIRMINGHAM LOCAL SECTION, *December* 18, 1908,
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The present paper consists merely of a few brief notes and suggestions, and does not attempt to deal with the subject in a comprehensive way, the object being to draw attention to certain possibilities in the way of commercial developments that, as far as the author is aware, have been somewhat overlooked.

The question of long-distance power transmission will first be considered.

I. Overhead Lines.

The cost of long-distance 3-phase overhead lines may be divided up into the cost of copper and the cost of supports.

The capital cost of copper at £60 per ton, employing an initial voltage of 270 volts per mile of line, a current density of 250 amperes per square inch, and a combined drop of 35 volts per mile, amounts to roughly £20 per effective kilowatt transmitted, assuming power factor equal to 80 per cent.

On a 100-mile line this would mean an initial voltage of 27,000, a total combined drop of 13 per cent., and a capital cost of £20 per kilowatt transmitted, which, on a 25 per cent. load factor, and taking interest, sinking fund, maintenance, and depreciation at 25 per cent. per annum, would mean a charge of roughly ½d. per unit transmitted.

By increasing the length of line to 122 miles, the line voltage being kept at 27,000, the capital cost per kilowatt would be increased to £30 per kilowatt transmitted.

So much for the copper part of the line; now for the supports. For light lines we may, perhaps, take £200 per mile as a minimum figure, while for heavy lines £500 per mile may be easily reached, excluding wayleaves.

Assume the power delivered to receiving end of line to be, say, 10,000 k.w.; this would require the heavier line construction, but, on the other hand, the cost per kilowatt would come out less than if we took a much lighter line, suited to the cheaper posts and insulators.

A line 100 miles long would, therefore, cost £50,000, or £5 per kilowatt transmitted for the capital cost of poles and insulators.

The smaller line, for, say, 1,000 k.w., would have cost £20 per kilowatt transmitted, for the same items.

It will be evident that on copper figures, and with a limit of 27,000 volts and 10,000 k.w., 100 to 120 miles is about the economical limit for the bulk of the transmission, and 50 miles with 1,000 k.w., except where coal is very dear.

In Fig. 1 a curve is given connecting copper cost per kilowatt transmitted with length of line, for a given percentage volt drop and a given initial voltage.

In Fig. 2 is given the cost per kilowatt for the supports, plotted with length of line, for different kilowatts transmitted.

It will be granted that any means which would halve the cost of the copper in the line would virtually increase by some 30 to 40 per cent. the possible distance of supply (in bulk), and thus be extremely useful in bringing the water-power—which is mostly in inaccessible spots—to the big towns, where there is a demand for the power.

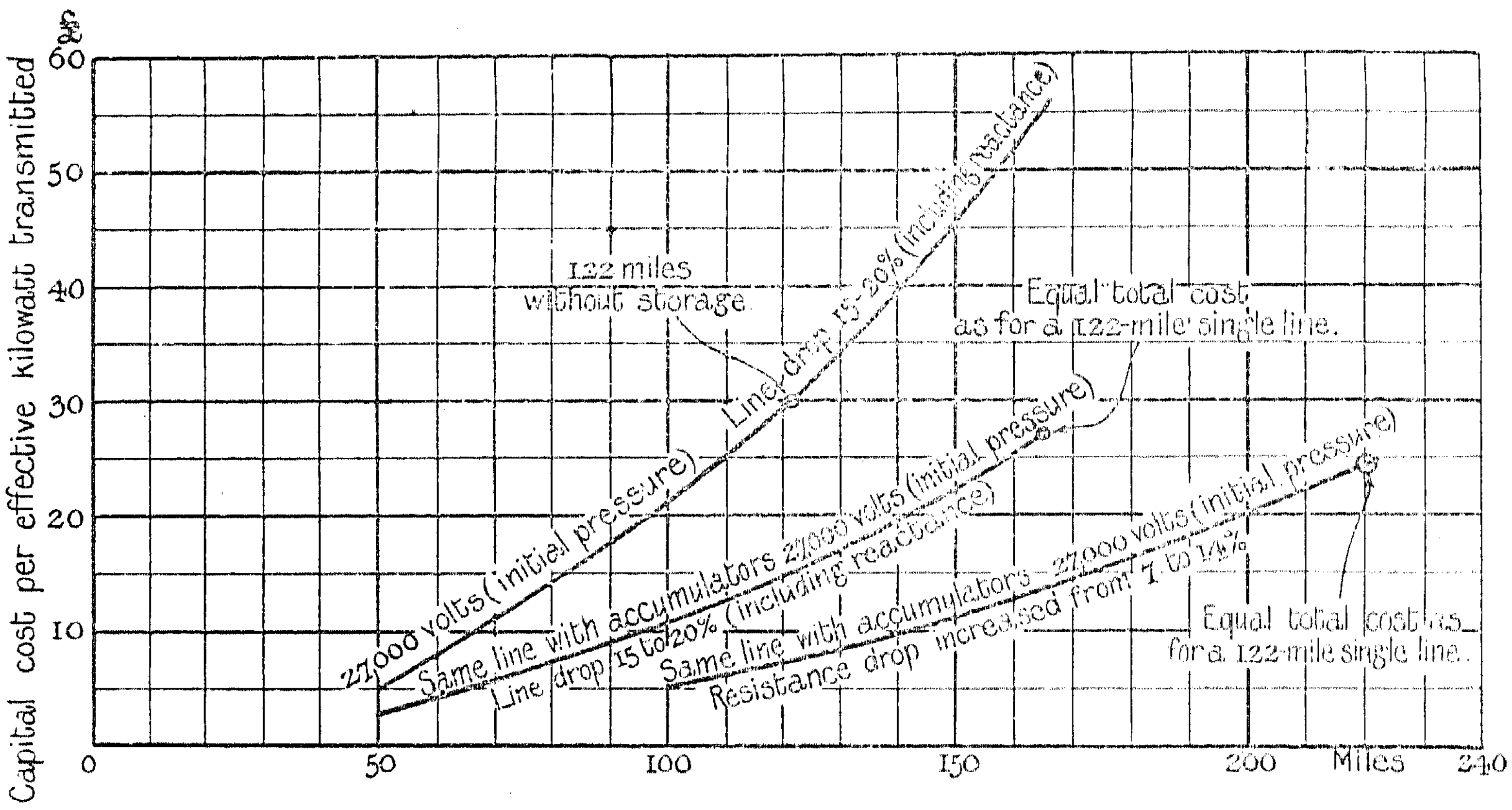

FIG. 1.

It will probably be also agreed that in many cases, especially where the line has to traverse mountainous districts for many miles, and is subject to interruptions through difficulties of inspection, etc., it becomes desirable to duplicate both poles and wires, and the cost of the line is thereby doubled.

The author's proposal is that electrical storage on a large scale should be carried out at the distributing centres, the reliability of the line being thereby increased to an extent that would warrant a second line being dispensed with. At the same time, he hopes to show that it is not necessary to trade upon the latter assumption in order to show a case for storage.

The batteries would be arranged to take up 50 per cent. of the peak, thereby halving the copper costs for the line.

In the case of a 10,000-k.w. 122-mile transmission with a single line, it will be found that, without raising the E.M.F. or increasing the line drop, the radius of transmission can be extended to 165 miles for the same total capital cost of 30 + 6 = £36 per kilowatt transmitted.

To cover this distance, *with a single line,* and with the E.M.F. limited to 27,000 volts, would have cost, without storage, some £63 per kilowatt transmitted. The storage scheme is thus some £27 per kilowatt the cheaper, as far as the line is concerned.

If the 122-mile line above considered had been run in duplicate, as regards the copper, only one line of poles, however, being provided, the radius of transmission could have been extended from 122 miles to about 230 miles without increasing the capital costs of the line.

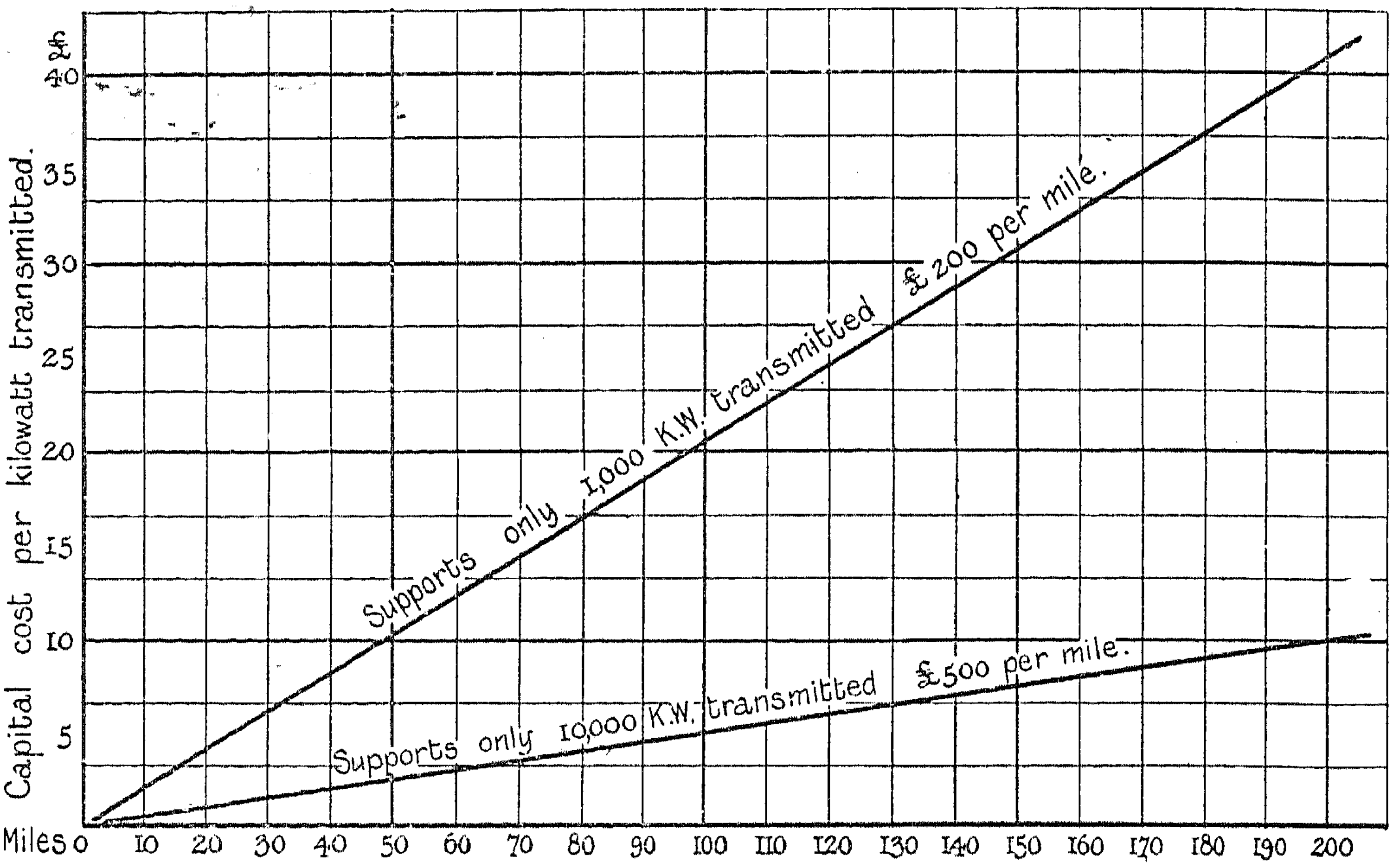

FIG. 2.

It will, no doubt, be objected that the author has taken too low a voltage, and that 50,000 volts might with advantage have been considered. But against this it may be said that the higher voltage brings its own disadvantages, and that, where the line has to pass through damp or smoky districts, the higher voltage would be risky.

Another point that makes for the reduction in voltage is the fact that the distributing part of the line not infrequently equals the transmitting part of the line in length or is worked at a lower voltage (as, for instance, the St. George's and Fabrezan transmission, referred to later). Consequently, the total cost of the line and distributors will really be that of a line working at an average voltage much below that of the initial voltage; and any saving effected on the first part of the line is, in part, compensated by the cost of the extra step-down transformers and the higher insulation wanted throughout the high-tension section.

In the example already considered, the resistance loss would be 8 per cent., and with a current density of 400 amperes per square inch, this might be run up to 16 per cent. With a battery at the distant end of the line a much greater resistance drop than 8 per cent. could be allowed in the line without the regulation of voltage being seriously affected; and it will probably be conceded that, in most cases, a greater resistance drop will be considered preferable to the risks introduced by increasing the voltage.

One disadvantage of the lower voltage would be the considerably increased reactance on such a line; but the reduced generator capacity caused by this can be eliminated at moderate cost, and the author has definite proposals to make in this connection, but to touch upon these now would unduly lengthen the present paper.

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It will, of course, be understood that, whether 50,000 volts or 30,000 volts be employed, the percentage increase in the length of the line effected by the use of accumulators, for a given total copper cost, remains unaltered; but the item for supports is evidently greater, in proportion to that for the copper, with the higher voltage, and somewhat reduces the length that would otherwise be permissible.

If, as suggested above, we take account of the much greater facilities for regulation provided by the employment of storage at the receiving end of the line, it will be found possible to double the resistance drop in the line and thus roughly to double the distance of transmission. Thus, the 122-mile single line considered in Fig. 1 *could be lengthened to 220 miles*, without any additional cost being incurred on the line, by the employment of storage; while, had the line been originally laid out in duplicate (as far as copper is concerned), it could have been extended to 304 miles for the same total cost in copper and supports.

The author suggests that, considering the desirabilty of being able to shut down one half of the line copper for repairs to insulators, etc., it will often be found advantageous to provide the spare copper circuit, where there is no storage. With storage at the consumer's end of the line, it is, of course, possible to deaden the line at certain times of the day without interrupting the supply.

The batteries and auxiliaries required for storage can in most, if not in all, cases be provided for out of the saving in generating plant, step-up and step-down transformers, turbines, head works, and buildings, only half the horse-power being needed that would otherwise be required.

Where the heads of water are low, the costs of the plant and head works run up rapidly, as will be seen from Table A, which gives the costs stated to have been incurred in some of the Swiss water powers, the average figure being about £73 per kilowatt.

On falls such as these the saving in generating plant and head works would suffice to extend the line to no less than 210 miles without increasing the total capital cost of the scheme, as compared with a single-line 122-mile scheme without storage. The further extension, due to saving in line copper, has of course to be added.

The cost of batteries to deal with a load curve of the type shown in Fig. 4 would be about £10 per kilowatt, to which about £3 10s. per kilowatt must be added for auxiliaries and accessories, on alternating-current systems.

Where the batteries cannot be paid for out of the saving in generating plant, they must, of course, be paid for in part out of the line savings; *i.e.*, the full benefit of the increased lengths above indicated, cannot be obtained.

TABLE A.*

	Cost of Power Station (Exclusive of Lines).	Horse-power Installed.	Horse-power Demanded.	Cost per Horse-power Demanded.	Cost per Kilowatt Demanded.
	£			£	£
La Goule ...	57,300	3,650	1,700	34	48
Geneva ...	280,000	12,000	8,100	26	37
Lintnal ...	16,500	1,000	510	32	46
Hauterive ...	260,000	7,200	4,900	54	77
Mont Bovoa ...	232,000	5,400	2,650	88	125
Kubelwerk ...	270,000	4,200	3,000	69	98
Fihl	104,000	2,000	1,960	52	74
Wynan ...	120,000	5,750	2,800	43	61
Hagneck ...	216,000	5,200	2,700	80	114
Beynan ...	341,000	11,700	8,450	40	57

The advantage of having a standby at the consumers' end of the line, equal to the maximum capacity of the whole scheme for short periods, is one which, of course, cannot easily be expressed in monetary value, but is nevertheless very great.

The savings on a large power transmission scheme by the introduction of storage are not confined to the items above considered, such fixed charges as wages, management, taxes, water-power purchase rights, etc., being *all* reduced with the reduction in the rated size

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[*] *Electrical Engineer*, vol. 41, p. 452, 1908.

the generating station and line; and these would, of themselves, the author estimates, alone more than pay for the cost of maintenance of the batteries and auxiliaries.

II. UNDERGROUND CABLES.

The author believes that similar arguments to the above will influence those power companies which have to cover large areas, in the direction of putting down accumulators at the distributing centres, or offering their customers such terms for current during restricted hours, for charging purposes, as will induce them to put down accumulators themselves.

Take the case of a small town on the outskirts of a power company's area. If the power company has to run a special feeder out to that town, it may easily happen that the costs of that feeder, especially if in duplicate, may run into £10, or more, per kilowatt of maximum demand, and, if the load factor is low, this is a serious item.

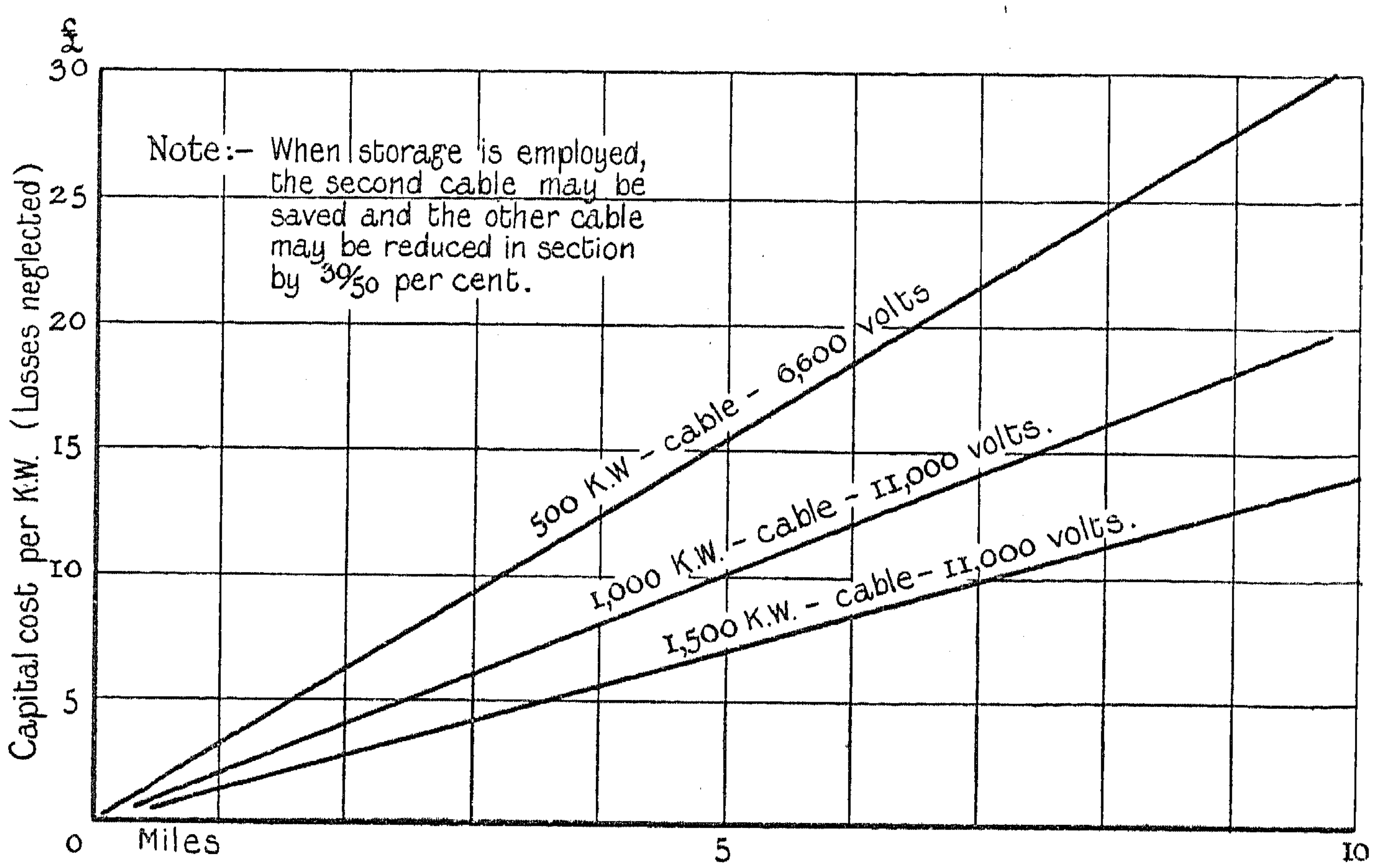

FIG. 3.

In this case the savings in fixed charges at the generating station, as the author has shown in a recent article,* would alone pay for the cells, and the saving in the feeder could be put down as clear profit.

Or, again, a power company covering a very large area and confined, by lack of facilities for cheap power production, to one part only of this area for its generating station, might find it practicable to reduce materially the costs of its general transmission and distribution system, as well as improve the reliability thereof, by employing large batteries in its own sub-stations.

To emphasise the importance to a power company of the saving that might thus be effected in underground feeders, the author has plotted the costs for duplicate underground feeders for three different sizes such as would be run to a small town. These costs are plotted in Fig. 3. They are taken from curves given in a paper by Mr. J. F. C. Snell.*

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* *Electrician*, vol. 62, p. 305, 1908.

It will be seen from these figures that if a power company had to run a special feeder 10 miles long to pick up the load of a small town, it would cost them, if the load was not above 1,000 k.w., something like £20 per kilowatt, if the feeder was laid in duplicate. Much greater reliability of supply could, with storage, be obtained with a single feeder of only 50 to 60 per cent. of the sectional area of one of the others, the capital cost in such case being not much more than half. The battery costs need not be debited to the feeder, for they will be saved over again in other directions, and the result is a clear saving in feeder outlay of £8 to £10 per kilowatt—enough in some cases to make the difference between profit and loss.

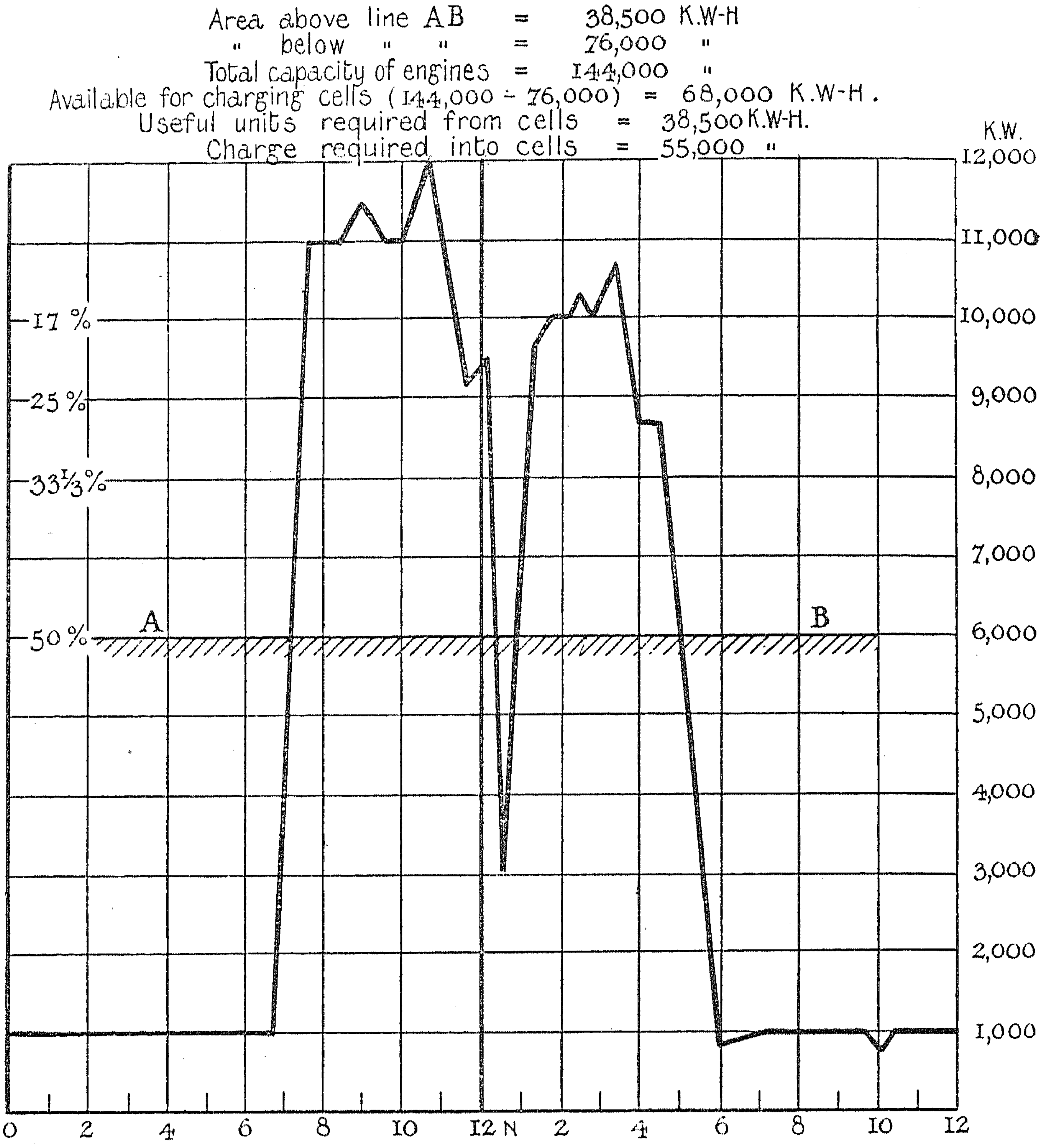

FIG. 4.

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* *Journal of the Institution of Electrical Engineers*, vol. 40, p. 288, 1908.

The diagram will also serve to emphasise the importance of any saving which a power company may make in its general transmission system, such as it would do by installing battery sub-stations at suitable points.

In this connection the author would like to call attention to, in his opinion, a somewhat prodigal provision for generating stations made by several of the power companies, as indicated in the maps of areas of these companies, published in the *Electrician's* Annual Tables (accompanying the issue of January 1st of that paper).

A glance at these maps will show that generating stations are projected, at the following distances apart, in the case of :—

North Metropolitan Electric Supply Company		9	miles apart.
South Wales Electrical Power Distribution Company		12	,,
Clyde Valley Electrical Power Company ...		16	,,
Yorkshire Electric Power Company	(*a*)	12	,,
	(*b*)	18	,,
Fife Electrical Power Company	(*a*)	6	,,
	(*b*)	13	,,
Lothians Electric Power Company	(*a*)	7	,,
	(*b*)	12	,,
Leamington and Warwick	(*a*)	9	,,
	(*b*)	12	,,
Derbyshire and Nottingham	(*a*)	8	,,
	(*b*)	15	,,
Cumberland E.P.G. Company		8½	,,
Gloucester E.P. Company		13½	,,
Somerset E.P. Company...		10	,,
Kent E.P. Company	(*a*)	12	,,
	(*b*)	26	,,

NOTE.—(*a*) signifies possible alternative sites for station ; (*b*) signifies do not appear to be alternative sites.

Diagrams are given of the stations scheduled or equipped by the first six companies (see Figs. 5 to 10).

In view of the saving, both in capital cost and in working expenses, of large stations as against small ones—the saving in the former being given by Mr. Addenbrooke recently as amounting to £17 per kilowatt of maximum demand, exclusive of distribution, as between 2,500 k.w. and 40,000 k.w.—the author thinks that sufficient attention has perhaps hardly been paid to the desirability of covering a large area from a given power station, even, if necessary, at rather higher costs for distribution.

Mr. Addenbrooke, it is true, shows *reduced* costs for distribution with the larger stations, but this can only be, the author thinks, on the assumption that the larger stations were put down in the more densely populated districts, and required less cable per kilowatt connected.

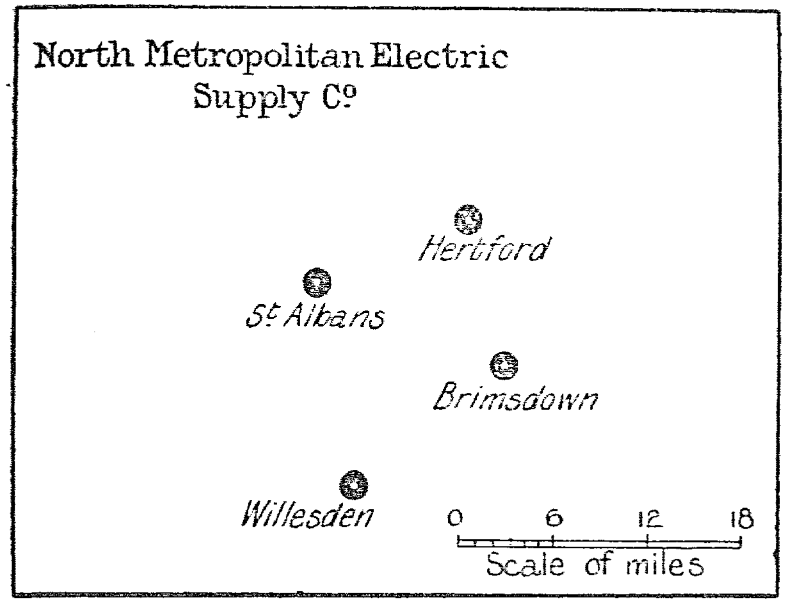


FIG. 5.

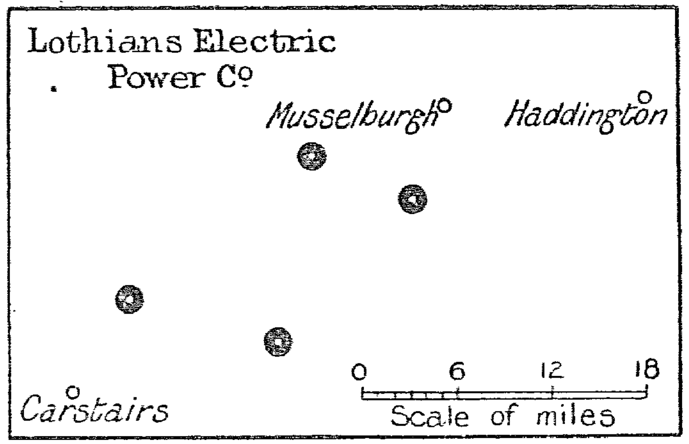


FIG. 6.

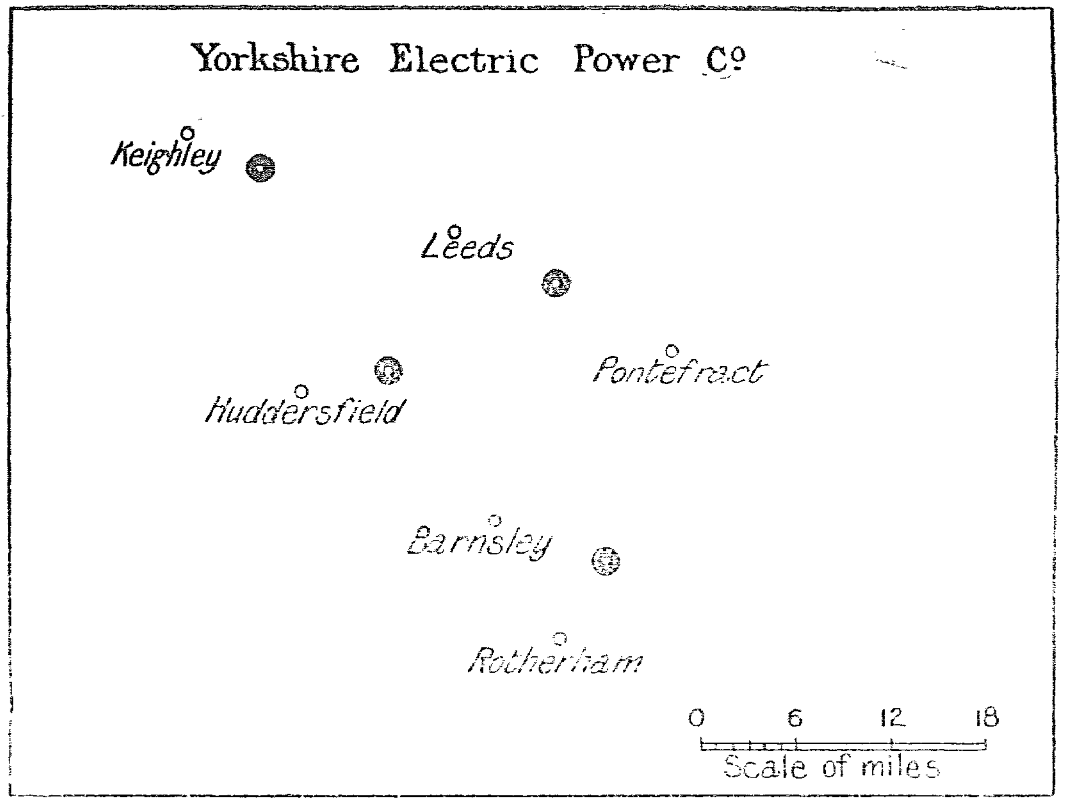


FIG. 7.

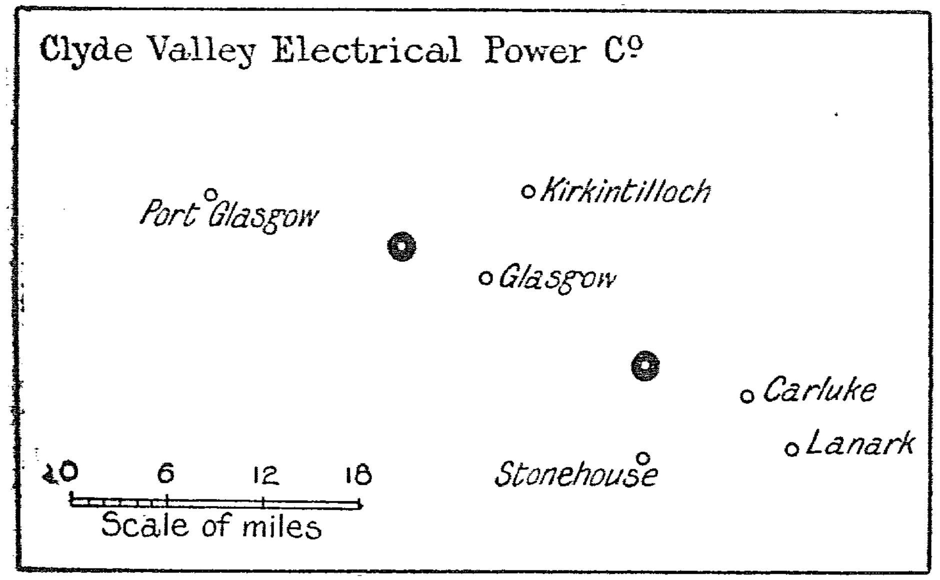


FIG. 8.

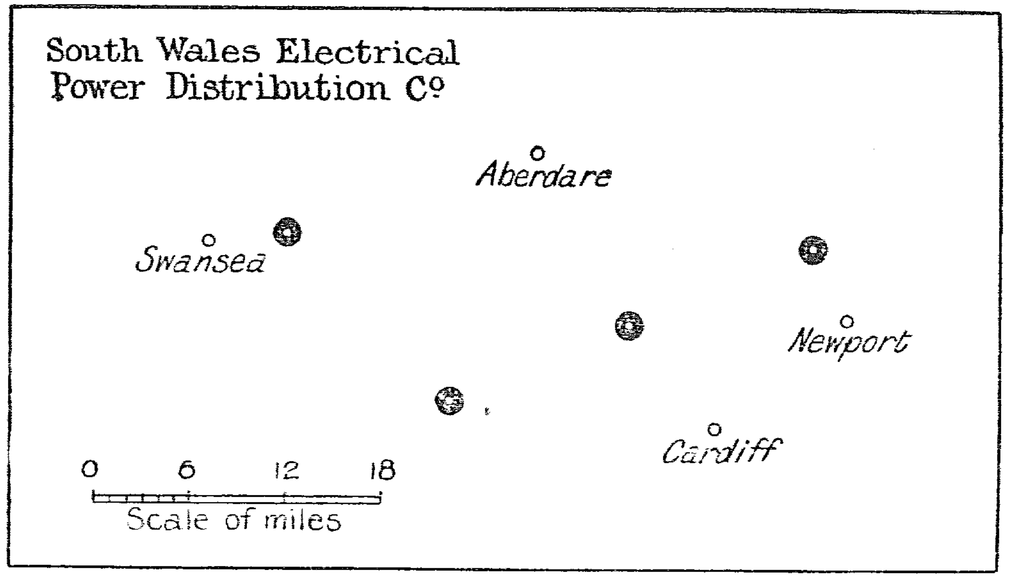


FIG. 9.

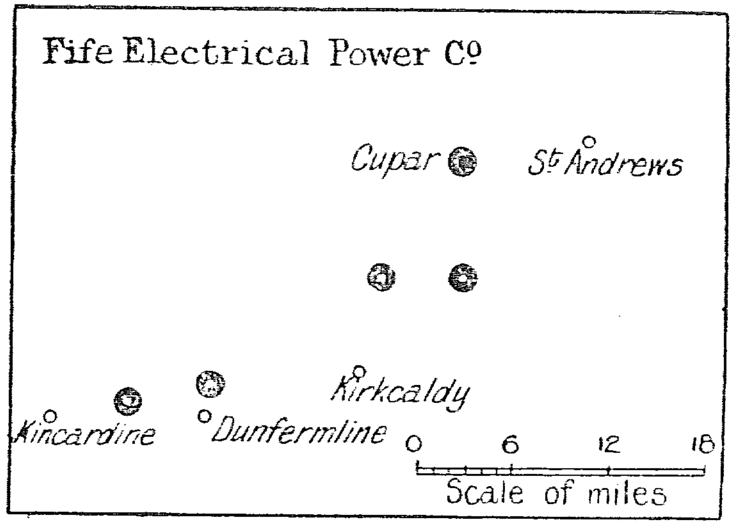


FIG. 10.

It is found that, with 10,000 volts and 1,000 amperes per square inch, the resistance drop amounts to 7½ per cent. per 10 miles. Since, in the early stages of the scheme, it would be most unlikely that the current density would average, throughout the length of the cable, anything higher than 500 amperes per square inch—take, for instance, the (existing) Power Company's scheme illustrated in Fig. 12—the drop on a 10-mile radius may probably be taken as not exceeding 3¾ per cent. It would therefore look as though it would have been safe to space the stations, say, 18 to 20 miles apart instead of 10 to 12

Analysis of Section Marked B *in Fig.* 11.

Element of Route.	Decrement of Load. Kilowatts.	Load on Element. Kilowatts.	Amperes at 10,000 Volts.	Length in Yards.	Current Density.	Per Cent. of Drop.
No. 1	800	1,800	108	2,053	1,000	0·87
" 2	50	1,000	60	1,760	555	0·41
" 3	200	950	57	2,640	527	0·59
" 4	200	750	45	352	417	0·06
" 5	200	550	33	800	306	0·10
" 6	50	350	21	1,320	194	0·11
" 7	100	300	18	3,226	167	0·23
" 8	200	200	12	350	111	0·02
	1,800	—	—	12,501	—	2·39

Analysis of Section Marked C *in Fig.* 11.

No. 1	50	1,650	99	1,760	1,000	0·75
" 2	200	1,600	96	782	970	0·32
" 3	450	1,400	84	2,110	848	0·76
" 4	400	950	57	440	576	0·11
" 5	100	550	33	2,465	334	0·35
" 6	100	450	27	3,190	272	0·37
" 7	50	350	21	3,270	212	0·29
" 8	200	300	18	390	182	0·03
" 9	100	100	6	295	61	0·01
	1,650	—	—	14,702	—	2·99

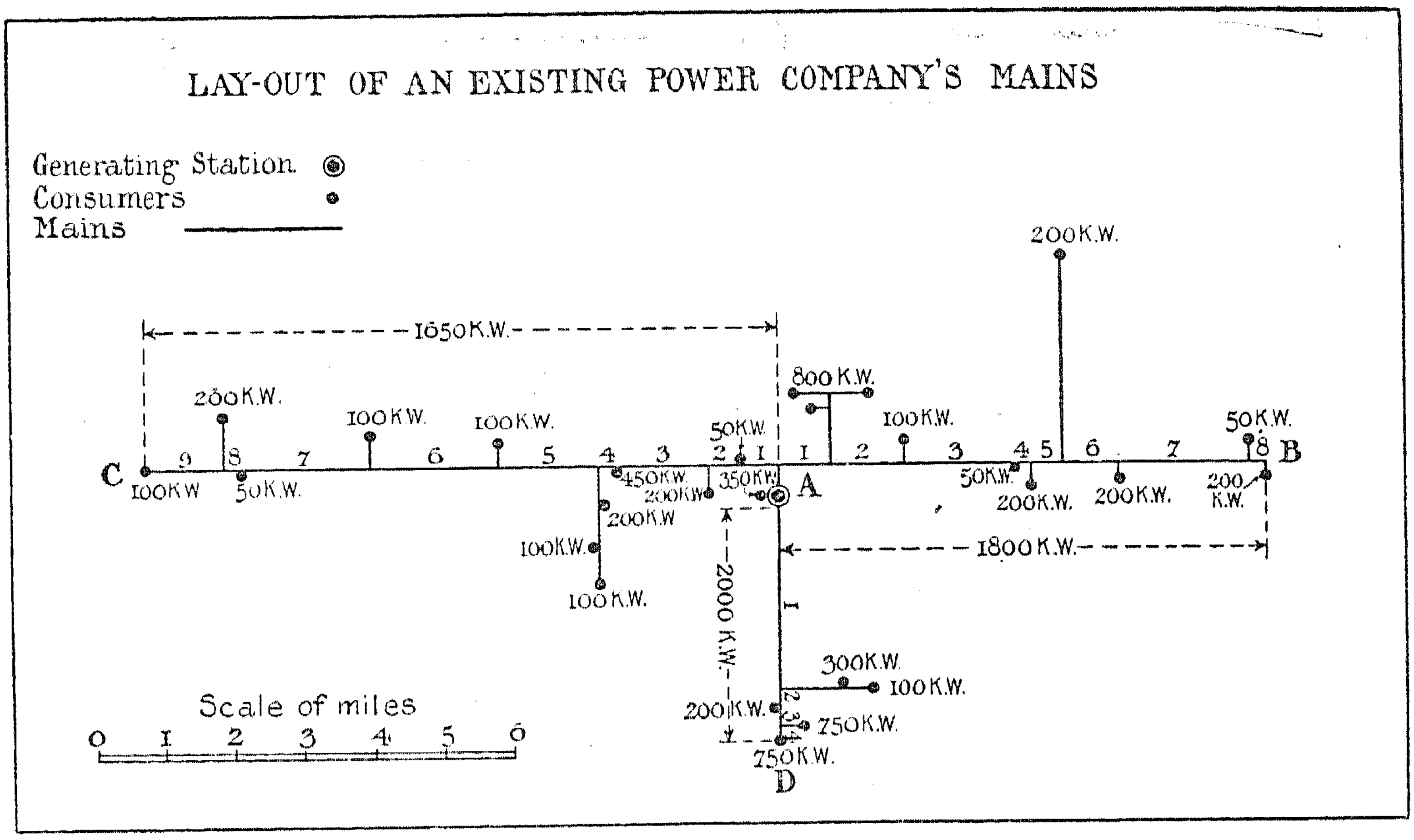
Analysis of Section Marked D *in Fig.* 11.

No. 1	400	2,000	120	4,840	1,000	2·06
" 2	100	1,600	96	390	800	0·17
" 3	750	1,500	90	390	750	0·12
" 4	750	750	45	220	375	0·03
	2,000	—	—	5,840	—	2·38

miles apart, as obtains in several cases in the above table, and to put down transformer sub-stations, where the voltage could be boosted up if necessary.

The author suggests that, where accumulator sub-stations are put down for dealing with the peak of the load, the load transmitted at the time of the peak can in some, if not in most, cases be reduced to one-half, and in others may be reduced to nothing.

This may be taken advantage of, either to cut down copper and save in capital outlay in the transmission line, or to double the *length* of that line and increase the distance between generating stations from 18 miles to 36 miles. It will be granted that the voltage regulation at the boundaries of the system will be so improved by the employment of the battery sub-stations that a greater loss in transmission may be allowed, and thus sufficient copper be saved to double the length of the copper conductor and pay for the cost of insulating, armouring, and laying the additional length.



LAY-OUT OF AN EXISTING POWER COMPANY'S MAINS

FIG. II.

It will also be granted that such an extension of the radius of supply would, in many cases, represent quadruple the load on a single station, and enable companies supplying sparsely populated districts, or large areas, to avail themselves of the saving in the capital invested in, and in the working expenses of, the generating station, which Mr. Addenbrooke very rightly pointed out can be made.

GENERAL.

It will, no doubt, be readily conceded that any means that will permit of a battery installation on either a water-power scheme or

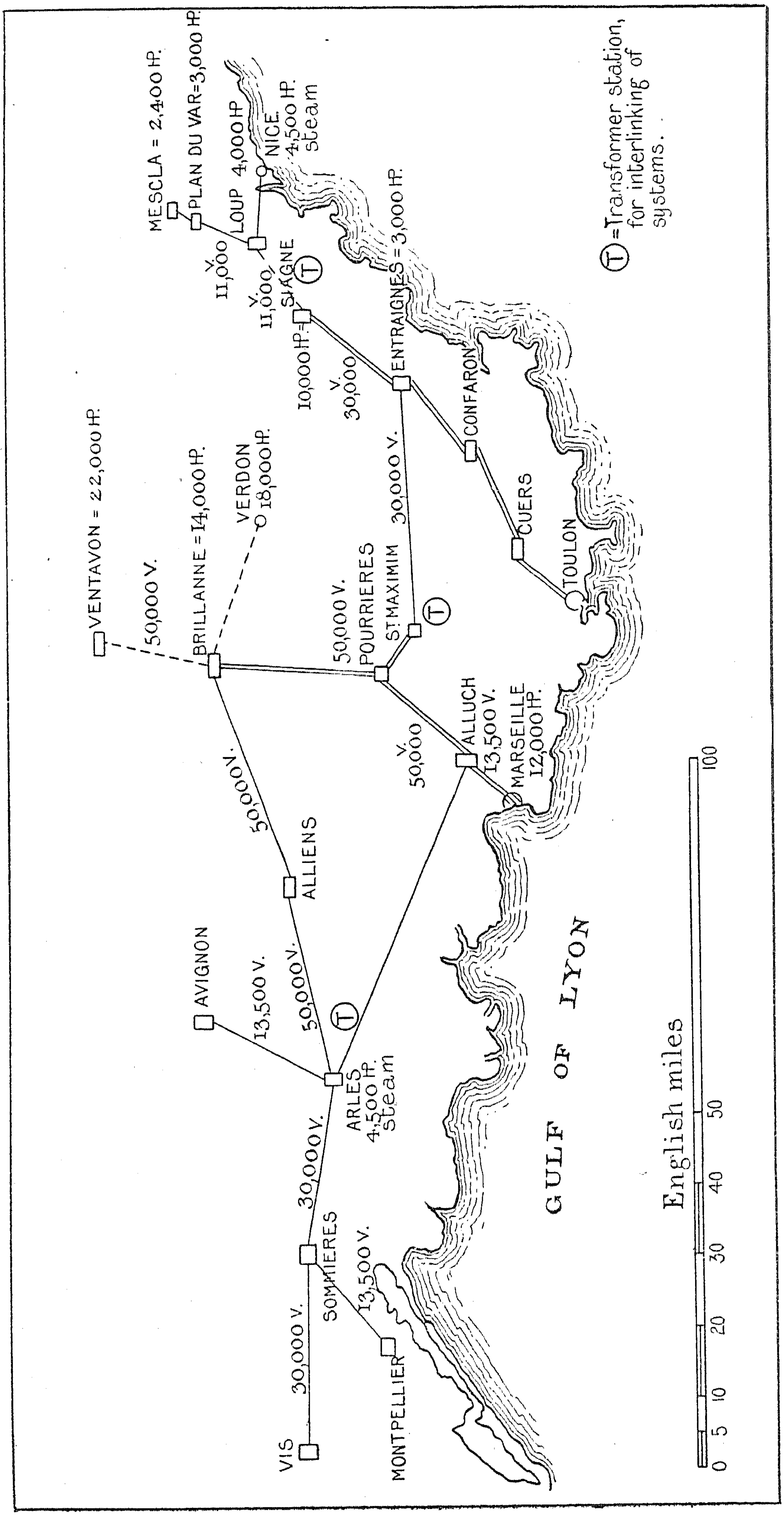

MESCLA = 2,400 HP.
PLAN DU VAR=3,000 HP.
LOUP 4,000 HP.
NICE
4,500 HP.
steam
V.
11,000
V.
11,000
SIAGNE
10,000 HP.
V.
30,000
ENTRAIGNES = 3,000 HP.
CONFARON
CUERS
TOULON
T = Transformer station, for interlinking of systems.
VENTAVON = 22,000 HP.
50,000 V.
BRILLANNE = 14,000 HP.
VERDON
18,000 HP.
30,000 V.
ST MAXIMIM
50,000 V.
POURRIERES
T
ALLUCH
13,500 V.
MARSEILLE
12,000 HP.
V.
50,000
50,000 V.
ALLIENS
AVIGNON
13,500 V.
50,000 V.
T
ARLES
4,500 HP.
steam
30,000 V.
SOMMIERES
13,500 V.
30,000 V.
VIS
MONTPELLIER
GULF OF LYON
English miles
0
5
10
20
30
40
50
100

FIG. 12.

a power company's scheme being commenced with a minimum of outlay and a maximum of reliability is to be welcomed. When put down on the lines usually followed, accumulator batteries do not readily lend themselves to extensions, without a great sacrifice in floor space and a considerably increased capital expenditure above what the author considers necessary.

In accumulator sub-stations with alternating currents, there is not much experience to go on in this country; but in the United States considerable attention is apparently being given to the use of rotary converters—whether of the "split-pole" type or of the "booster" type —in conjunction with storage batteries on alternating-current systems. The author has proposals of his own to make in this connection; but prefers to wait till they have been put to the test of experience before bringing them up for discussion at this Institution.

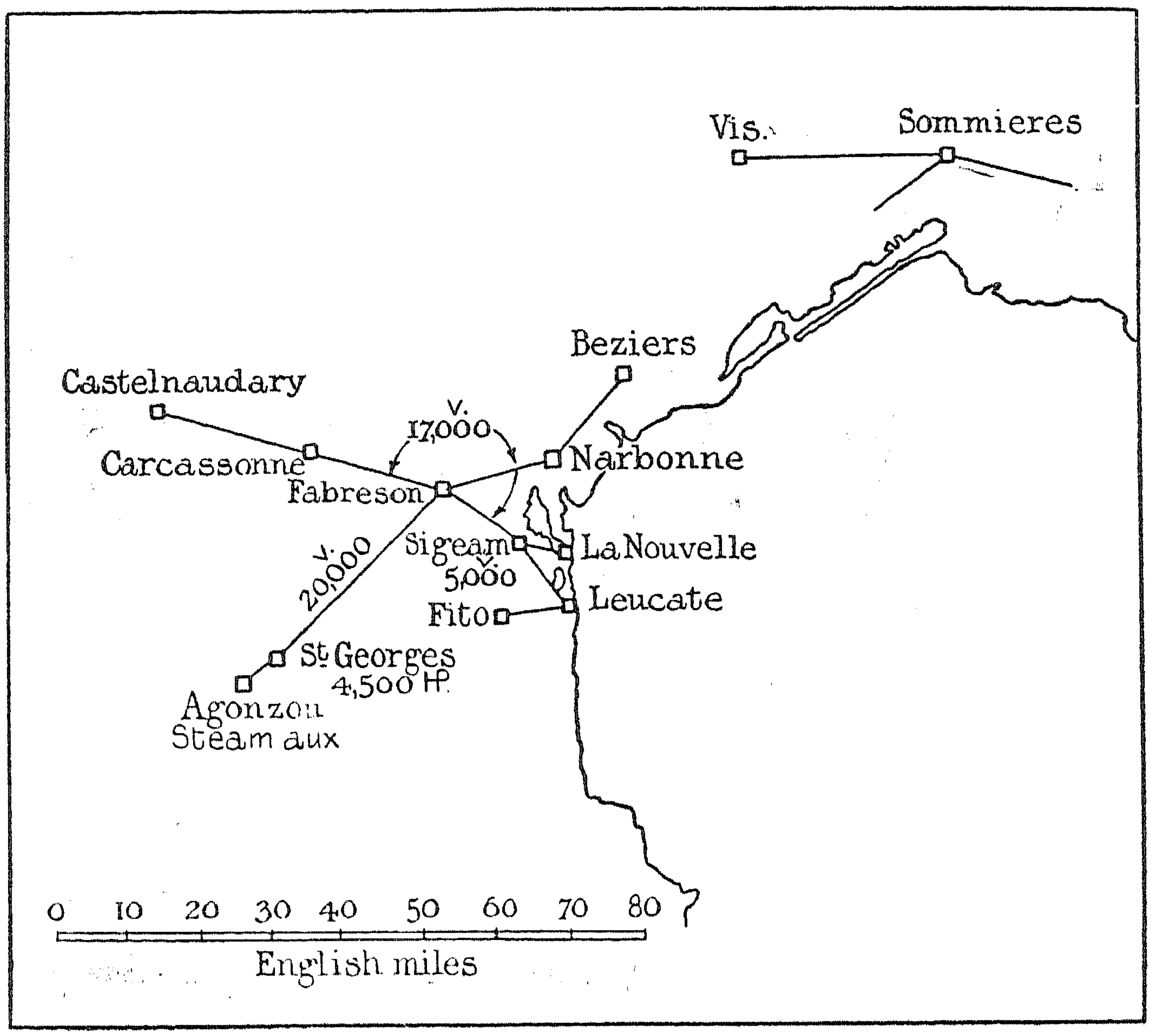


FIG. 13.

It might be thought at first sight that the energy losses on an alternating-current scheme would be serious, but, on a water-power scheme, the cost of each unit of electricity put into the battery, if put in at suitable times, is only of the order of 0·05d.; consequently, neither the efficiency of the rotary converter nor that of the battery is so important as to weigh seriously in comparison with the charges on the line and generating plant.

HIGH-TENSION POWER TRANSMISSION IN EUROPE.*

A recent issue of the *Electrotechnik und Maschinenbau* (vol. 26, p. 1058, 1908) gives the following list of undertakings in Europe whose transmission voltage exceeds 30,000 volts :—

	Voltage.	Date of Opening.	Capacity.	Length of Transmission Line.	Contractors.
			Kilowatts.	Kilometres.	
Heimbach (Ruhrtalsperren-Ges.), Aachen	34,000	1904–5	3,090	143	Siemens-Schuckert
Munich (Moosburg)	50,000	1906–7	4,000	56	Siemens-Schuckert
†Hamburg—Altona	30,000	1906–7	5,600	14·6	Siemens-Schuckert
Kykkelsrud, Norway	50,000	1907	3,000	42	Siemens-Schuckert
Sociedad Hydroelectrica Iberica, Spain	33,000	1903–5	10,000	200	Siemens-Schuckert
Lagunas de Ruidera, Spain	30,000	1903–6	1,050	—	—
Sociedad Hydroelectrica Espanola Molinar	66,000	In course of erection	25,000	250 to Madrid 120	Siemens-Schuckert
Madrid	30,000	1901	3,000	—	Kolben & Co.
Zamoro, Spain	40,000	1906–7	3,300	40 to Valladolid	Alioth & Co.
Sociedad Hydroelectrica de Guadiero, Spain	50,000	1906–7	4,500	130	Maschinenfabrik Oerlikon
Bilbao, Spain	33,000	—	3,460	120	—
Caffaro, Lombardy	40,000	1906	10,000	50	Maschinenfabrik Oerlikon
Montereale an der Cellina, Lombardy	36,000	1905	7,000	33 to Venice	Brown, Boveri & Co.
Gromo, Lombardy	40,000	1906	3,000	34	Brown, Boveri & Co.
Tusciano, near Clevano	30,000	—	7,000	—	Westinghouse
Bournillon, France	35,000	1905	1,000 H.P.	—	—
La Plombière, France		1906	3,000	200	Comp. de l'Industrie Électrique de Geneva
Saint-Cézaire, France	30,000	1906–7	5,700	60 110	Thomson-Houston
Durance Station, Marseilles	50,000	—	15,000	—	—
‡Moutiers—Lyons	57,000	April, 1906	4,100	130	Comp. de l'Industrie Électrique de Geneva (Thury System)

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* *Electrician*, vol. 62, p. 509, 1909. † Single phase. ‡ Direct current.

On a power company's distribution scheme, where the power is generated by steam, the cost of the energy put into the cells for charging purposes is only of the order of 0·10d. per unit; so that here again the efficiency of the rotary converters and of the battery is not so important as might be thought.

To engineers interested in the general question of batteries used in the sub-stations of alternating-current and direct-current systems to take up the peak of the load, the author would here state that some of the points raised in this paper will be found more fully discussed in a recent article,* and in a paper read by him before the Municipal Electrical Association on July 3, 1908, entitled "Alternating-current Accumulator Sub-stations."

Fig. 12 shows a plan of the system of the Société Energie Electrique du Littoral Mediterranée; and for further particulars of these systems members are referred to the article by Dary. †

A plan of the area fed by the water-power transmission system of the Société Meridionale de Transport de Force is given in Fig. 13.

DISCUSSION.

Mr. Chappell.

Mr. W. E. CHAPPELL: I regret that I am unable to agree with some of the statements put forward by the author of the paper. He estimates £500 per mile as a price which might easily be reached for the supports of a heavy overhead line. It may be interesting to know that for £293 per mile it is possible to supply and erect the steel towers of a thoroughly up-to-date line for transmitting 10,000 k.w. at a pressure of 40,000 to 60,000 volts. This price also includes the cost of the line insulators on voltages up to 60,000. It would not be policy to employ wooden poles, as the depreciation is very great, being about 10 per cent. on the poles, 12½ per cent. on the insulators, and 5 per cent. on the copper. In a number of installations in the United States it has been the practice to supply transformers which can be adapted for either 40,000, 50,000, or 60,000 volts, and to start the transmission at 40,000 volts. As the demand for energy increases, the transmission voltage may be raised. The author states that by employing a battery it would be possible to cut down the copper by 50 per cent.; but this is somewhat doubtful, and, furthermore, in putting up overhead lines, it is not so much the carrying capacity that determines the size of the cable as the length of span, the stresses due to wind pressure, and other conditions. In the United States there are five systems in operation similar to that proposed by the author, and the results obtained by the working of these systems have not been as good as the originators hoped. One of the systems has been abandoned, two of them are working fairly well, and the remaining two are anything but satisfactory. With reference to the author's statement that a battery would enable a portion of the line to be completely shut down for repairs, this is only possible if there are no consumers on that particular section of the line; and in supplying energy in bulk, the demand on a battery would be so great that it could not continue the supply for a longer period than two or three hours. Mr. Chappell.

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* *Electrician*, vol. 62, p. 305, 1908.

† *Electrical Review*, vol. 62, pp. 533 and 703, 1908.

Mr. Kemp. Mr. J. P. KEMP: I agree with Mr. Taylor that there is a good deal to be said for the adoption of accumulators, one point which appeals to me being the very high emergency value of a battery and the improved voltage regulation which its use ensures. I cannot agree, however, that the extraordinarily low cost of 0·1d. per kilowatt-hour is the correct charge for the energy put into the battery. Mr. Taylor has assumed the most ideal conditions, and is evidently basing his estimates on the fact that the battery charge is done without running any additional plant, but merely by improving the running plant load factor. There is, however, a limit to this, and it will sometimes be found necessary to run additional plant in order that the battery may be charged in the time allocated, in which case the cost of the energy would certainly exceed the figure he gives. The figure (0·1d. per kilowatt-hour) is not one which can be realised in practice, except possibly in a water-power scheme. I would like the author's opinion as to what percentage of the peak should be taken up by the batteries in the case of a combined traction, lighting, and power system like that at Birmingham; 50 per cent. seems to me too much to be seriously entertained, and I am not aware of any place where more than 10 per cent. of the peak has been taken up. With regard to Mr. Taylor's criticism of the positions selected by the various power companies as sites for their proposed stations, it ought to be borne in mind that, although the geometrical centre of the county might be an ideal position for a central generating station, there are numerous difficulties which, in many cases, prevent this from being carried out in practice.

Mr. Forrest. Mr. F. FORREST: The author's figure of 270 volts per mile seems unduly low in view of the success with which large transmission schemes operate at double this pressure. The current density he mentions—viz., 250 amperes per square inch—whilst being probably the economical limit for long lines, should certainly be greatly increased for short-branch networks if saving in capital cost is the chief object in view. The author makes a great point of the extra reliability attending the use of the batteries in sub-stations, and states that one line with batteries is as safe as double lines without them. I think it would hardly be wise to rely on the batteries, because in the event of a serious breakdown of the supply they would only be capable of taking the whole of the load for two or three hours; whereas, in mountainous country, it might easily take two or three days to locate and repair a fault in a 150-mile line. The author also states that, with batteries, it would be possible to lay the lines dead at certain times for repairs. If Fig. 4 shows an ideal load curve from Mr. Taylor's point of view, then it would be necessary to run machines night and day to charge the batteries or to run a share of the load. And when would the repairs be carried out? The author makes light of the question of the efficiency of his alternating-current battery sub-station; but engineers will hesitate to adopt any scheme which would undoubtedly involve loss of 45 per cent. of all units they generated.

Mr. Groves.

Mr. W. E. GROVES: I agree with the last speaker that a single line with a battery at the far end would be impracticable. The time taken to locate and repair a fault on the line cannot be predetermined, and unless the battery is of abnormal dimensions it will be no security against a shut-down. Batteries can only be used for saving copper within very definite limits, the minimum provision being mains in duplicate, each one capable of taking full load without damage to the cable or serious injury to the reputation of the supply authority should one main fail and the battery become exhausted. A shut-down due to accident to plant can usually be avoided by the installation of a battery, but the situation where a main fails is entirely different. In stating the case for batteries, therefore, we should not bring forward saving in copper in the line as an argument in their favour, though credit must be given for their useful qualities in respect of regulation, improvement of load factor, and reliability.

Mr. Boulton.

Mr. P. R. BOULTON: The cost of energy put into the battery even in a fairly large station must be nearer 0·2d. than 0·1d., the amount stated on page 438. A previous speaker has criticised the figure taken for current density, and has mentioned a much higher figure. It was, however, the voltage drop that was the determining factor, and not the heating limit. I think it might be possible, in connection with the author's scheme, to strike a compromise and employ batteries of a smaller capacity, thus reducing the losses incidental to their use, while at the same time obtaining the advantage of better regulation on peak loads.

Mr. Rosher.

Mr. N. B. ROSHER: Referring to page 424, I should like to know how the author arrives at his figure of 25 per cent. for interest, sinking fund, maintenance, and depreciation on the copper part of the transmission line. Assuming interest to be at the rate of 5 per cent. and depreciation and sinking fund 8 per cent., this will leave 12 per cent. maintenance, an extremely high figure, especially in view of the fact that the copper part of the line only is included and not the supports. Taking the author's figures of £20 per kilowatt as the cost of copper on a 10,000-k.w. 100-mile transmission line, the maintenance at 12 per cent. works out £2,400 per mile. I would also point out that the improvement obtained by the use of a battery to supply 50 per cent. of the peak load as shown in Fig. 4 would, when expressed in percentages, mean an improvement of at least 40 per cent. in the load factor.

Dr. Kapp.

Dr. G. KAPP: The idea of using batteries to extend the radius of transmission has already been applied, though perhaps not in the extensive and perfect manner advocated by the author. Many will remember that even in some of the earliest electric railways batteries were put into sub-stations placed about one-third from the end of the line, the object being to equalise the load on the generating plant and reduce the cost of the feeders. Table A on page 428 does not seem to bear out the author's contention that a low fall water power is necessarily costly. The highest cost in this table is given for the Kubel plant, but there the fall is very great, in fact so great that Pelton wheels had to be installed.

Dr. Kapp.

The reason why some of the Swiss water-power stations are costly lies in the fact that in many cases a steam reserve has to be provided. The power being derived from glacier streams is greater in summer than in winter, so that just when most power for lighting is wanted the streams carry least water, and the provision of a steam reserve becomes a necessity. I agree with Mr. Addenbrooke that engineers have not overlooked the possibility of using the accumulator as a means of extending the area of the district served, but they naturally shirk the financial responsibility. I might mention a case in point where the use of accumulators has been fully considered and then abandoned. This was in the remodelling of the public supply of the town of Lucerne. Originally Lucerne was served on the single-phase system by two stations—one water, the other steam power. Then the town acquired a large water power in Engelberg, and this was transmitted to Lucerne and distributed by means of the old network, which was perfectly serviceable. But the question had to be faced as to what would happen if the transmission line were interrupted. To provide against this, two methods of accumulating energy were discussed, one by batteries and the other by the creation of an artificial reservoir on a neighbouring mountain into which water would be pumped when there was a surplus of power. The hydraulic storage scheme appeared to the engineers rather the safer of the two, and in planning the sub-station the possibility that at some future time such a system of storage might have to be adopted was kept in view. It was not a new departure; there existed already at that time in Switzerland one installation where the principle of storing energy in an artificial high-level reservoir had been put into practice. This is in Canton Aargau, and the work was carried out by Messrs. Brown-Boveri. The efficiency can naturally not be very high, about 50 per cent. or thereabouts, but as the energy required to pump up the water is surplus energy costing practically nothing, and the maintenance cost of the hydraulic works is very small, there is a clear gain by this kind of storage. I might mention that in connection with the large power station now being erected by the town of Bale on the Rhine at Augst, provision is being made for hydraulic storage, if at a future time it should be required, the site for the future reservoir being on a high plateau on the right bank of the river.

Mr. Addenbrooke.

Mr. G. L. ADDENBROOKE (*communicated*): The main object of the paper, I take it, is to show that by the use of accumulators at the distributing end of feeders the copper section in them might be reduced or their length correspondingly increased. To avoid getting involved in a mass of figures, I think I shall do best to relate my own experience in the matter. In my paper on "High-Voltage Lamps and their Influence on Central Station Practice,"* written before the great extensions in distribution at 400 to 500 volts had taken place, very full data as to the cost of feeders were given. Considerable space was devoted to this method of using accumulators, very closely on the lines Mr. Taylor is now advocating, and I think he will find, if he will look

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* *Journal of the Institution of Electrical Engineers*, vol. 25, p. 208, 1896.

Mr. Addenbrooke.

the paper up, that very much the same arguments were used in their favour, together with similar estimates of their costs. I see that at that time, just thirteen years ago, the cost of accumulators was put down as £13 for the battery alone, as compared with the £10 Mr. Taylor gives in his paper. Other costs for accessories, including buildings, brought up the capital cost to £19 per kilowatt as against £13 10s. in Mr. Taylor's estimate, although this does not appear to include buildings. Against this, in my paper the sum of £19 per kilowatt was taken as the cost of large central-station plant, whereas the cost at present would be about £13. Relatively, therefore, the position does not seem to have altered very much. On looking back over the practice of the last thirteen years, while the practice which I advocated as regards feeders has been largely adopted, several well-known central station engineers have from time to time also assured me that my figures were closely borne out in practice. On the other hand, it does not appear that the suggestions as to the use of accumulators on the ends of feeders have found general favour, not because the matter has been overlooked by engineers, but because each one took up the circumstances of his own particular installation, and has found that on the whole the balance of advantages did not warrant the outlay in accumulators, and it seems to me from the prices I have mentioned above the relative position has not altered very much since then, and therefore I take it that although the argument may be difficult to put on paper, yet when one comes to take specific projects, there are valid arguments sufficient to outweigh the apparent advantages which the use of accumulators would give. An economical and cheap method of storage has, of course, been always the ideal of the central station engineer, and I do not want to damp Mr. Taylor's ardour in the matter or to deprecate the very careful study of the question. There are cases, such as in the centres of large cities and where tramways have to be supplied, where the use of accumulators in the way suggested by Mr. Taylor is justifiable, and has been applied, and any improvements in accumulators or reduction in their capital cost would lead to extension of such applications. For instance, it has occurred to me that a very large power company or corporation supplying such a large amount of energy as we may contemplate in the future, might find that it paid them to run an accumulator factory themselves, doing their own repairs and making their own plates. If they could work on a sufficiently large scale they might be able to make plates at a sufficiently low figure to warrant their use on an extensive scale, but the time has hardly come when such a thing is practicable.

Coming now to the question of transmission lines overhead and underground, I think Mr. Taylor has perhaps not quite grasped the practical position. Assuming that a line of a certain capacity is erected, and the line is necessary in any case, the cost of double the section of the copper or of raising the voltage 50 per cent. is a comparatively small addition to the whole cost, and in this way the full demand can be met by supply from the central station. Again, I

Mr. Addenbrooke.

do not think it is altogether fair to base calculations on a line 100 miles long operated at 27,000 volts ; from the list of transmissions given in the paper it is clear that in modern practice at least 50,000 volts would be used for this, and I think with modern forms of insulators there would be no difficulty in running lines at that voltage even in this country. Doubling the voltage increases the amount of energy conveyed with the same percentage drop about four times, and alters the basis of calculation altogether. The same argument applies in connection with underground cables ; to slightly increase the section of the copper does not by any means proportionately increase the cost of the whole feeder, while with regard to the question of duplicate lines it is the object of power companies, as they extend, to work almost entirely by means of loops. There may be, from time to time, cases where the adoption of accumulators will be advantageous, as Mr. Taylor suggests, but I think we may take it that their advantages are fully understood by Continental and American engineers, and, if on the balance of arguments it had been found profitable to instal them in the manner suggested by Mr. Taylor, we should have already had more numerous examples.

Finally, I am glad to see the attention which Mr. Taylor has drawn to the work which is being done in France with overhead transmission, and particularly to the way in which, by carriage of these high-voltage lines across the country, the smaller townships and villages are able to secure the advantages of light and power. It has always been my view that there was room for work on the same lines in a considerable number of districts in this country if it could be carried out in the same way that it is being done abroad. In two or three instances I attempted to lay the foundations for such work, but much to my regret I found the legal and parliamentary obstacles so serious, and the demands of the local authorities so onerous, that I was reluctantly driven to the conclusion that until matters in these respects could be amended, there was little hope that capital could be profitably devoted to such purposes, however advantageous the results to this country. I trust that the publicity given by this paper to the methods of work in a neighbouring country may do something to draw attention to the matter, and lead to better facilities being given for enterprise in this direction.

Mr. Orsettich.

Mr. R. ORSETTICH (*communicated*): The question raised by the author is of great importance in the design of power-transmission plants, and one which in the last ten years has received a large amount of attention from engineers, owing to the difficulty of ascertaining beforehand with any accuracy the probability of profit of such large installations. A great many data as to the design and cost of some up-to-date plants have been published, and are available for use as a basis of similar calculations. I will give a few figures which I have collected, partly from previous work in this direction, and partly from some friends who work still in the same field. It appears to me that my figures differ to a considerable extent from those which the author

Mr. Orsettich. has taken as the basis of his views, and will therefore affect to a great extent the results arrived at.

Dealing first with the question of voltage, I think that the figure of 270 initial volts per mile is taken too low. The well-known American rule of thumb is 1,000 volts per mile for the first 3 miles and 400 volts per mile for each subsequent mile. In this way a transmission of 15 miles would require 7,800 volts, whereas only 4,000 volts would be considered necessary by the author. On a 100-mile line, instead of the 27,000 volts proposed, one would have to take 42,000 volts. If one considers that the cost of the copper is in inverse ratio to the square of the voltage the effect of the alteration would be easily seen. The figures stated can also be found in actual installations—for instance, the extension of the Vizzola Transmission in the north of Italy will work at a voltage of 45,000 for a maximum distance of 113 miles. The new plant that Messrs. Siemens have installed for the Spanish Hydro Electric Company is transmitting 16,000 H.P. (later 32,000 H.P.) 160 miles away with 66,000 volts. Further, some 12 plants in the United States, whose maximum distance is about 100 miles, are working with a voltage of 60,000 or thereabouts. The necessity of using high voltage in order to increase the range of operation is also borne out by the fact that several companies who in the beginning had put down a plant working at what was estimated at the time to be sufficiently high voltage, found out later that in order to obtain economical conditions of working they had to raise their voltage as soon as the experience gained in the working of the line enabled them to do so with safety. Examples of this are: The Electra Transmission of the Californian Gas and Electric Corporation, working in maximum of 154 miles, raised the voltage from 36,000 to 55,000; the Kander Works in Switzerland, working 28 miles, originally put down plant at 4,000 volts, which was raised later to 16,000 volts; the Beznau Works, also in Switzerland, with a distance of 29 miles, had to raise the voltage from 8,000 to 25,000.

Whilst agreeing with the author that a low voltage is safer and connected with several advantages, I think that the fact that high tension is being used to such a great extent in so many plants in different countries is sufficient proof of its practicability and reliability, and that such systems cannot be disregarded when considering from an economical point of view plants of the magnitude of 10,000 k.w. and a transmission of 100 miles. The other parts of the line affected by an alteration of the initial voltage would be the supports, the transformers, and the switchgear. The cost of the supports per mile of line are practically independent of the voltage, as the weight of the line and the cost of erection are reduced with increasing voltage, whereas the weight of the insulators increases with the voltage. Between 20,000 and 30,000 volts the cost of the supports to the line will only be increased by about 4 per cent., and between 20,000 and 40,000 by about 12 per cent. The cost of the transformers hardly varies at all between 20,000 and 30,000 volts, and about 8 per

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cent. between 20,000 and 40,000 volts. The switchgear remains practically the same, the lightning arrester only causing an increase in this item of 4 to 5 per cent. for 40,000 volts, compared with their cost at 20,000 volts. As, however, all these items taken together represent only an increase of about 28 per cent. of the cost for doubling the voltage to 40,000, it will be seen that this is entirely cancelled by the saving in the cost of copper, which will now be reduced to one quarter of the original amount. In addition to the above, the heavy amount put down by the author for the cost of copper has also to be accounted for through the limit fixed for the combined drop in the line. In my opinion, assuming that one should select such a low voltage as 27,000 for a 100-mile line, the combined drop should at least be fixed at 25 to 30 per cent. instead of 13 per cent. I explain later that the cost of producing the current in hydraulic installations is a fairly indifferent item, and that when the plant has to work with steam power the losses of the line do not come into account.

Some of the figures given by the author as to the cost of the supports for the line should also, in my opinion, be revised. A number of long transmission lines executed in the last five or six years in the north of Italy, and passing through a county which could not be called very favourably situated with regard to atmospheric conditions, were executed at a remarkably low cost. I refer more particularly to the flexible metallic supports arranged at great distances (about one-tenth of a mile) from one another with great sags in the lines. This type of support has also the great advantage of enabling a duplicate line to be used whenever required without necessitating a separate set of supports. A line of this kind fitted with 14 metallic supports to the mile, each suitable for six ⅜ in. diameter wires, would work out complete, including erection and insulators, but exclusive of copper, at £210 per mile. As a line of this kind must be included amongst the heavy lines, it will be seen that the cost is exceedingly low. The life of the metallic poles can be taken at about twenty to twenty-five years, and it therefore seems to me that the figure of 25 per cent. per annum included by the author for sinking fund, depreciation, and maintenance is very much higher than what is usually assumed to be a commercial figure.

To the proposed adoption of storage batteries in connection with long-distance transmission, I am afraid most engineers will have some grave objections. The principal one would be the necessity of converting the alternating current to continuous, with its well-known handicap of rotating machinery and expensive switchgear. Further, the range of distribution from each battery would be very limited on account of the low voltage, this in its turn requiring very expensive feeders and heavy drop, which will come in addition to the losses of transformation in the machines and in the battery. The limited range of each battery would involve the necessity of using a very large number of batteries. It is well known that the area of distribution is a very large one for most of the existing transmission lines, as is shown by the

Mr. Orsettich. fact that many times the distribution itself is done at 2,000 to 3,000 volts. The argument of the author that the use of batteries will not necessitate a second line of transmission because of the increased safety does not appear to me to hold good, as the battery would be only designed to supply the peak load, and therefore in the best cases to keep up the supply for half a day in case of breakdown. The peak itself is not of real importance as far as the line is concerned in an installation of this kind, because there is always a large amount of reserve in the generating station which can be used to overcome the drop of the line at the moment of maximum demand.

The real difficulty with hydraulic plants lies in the fact that the supply can be kept up only for nine or ten months at the most, and that a reserve in steam plant is necessary for the other two months. This steam reserve is always placed in the centre of the area of distribution, and the cost of the line therefrom affects in an entirely different way the current produced under these circumstances. Whether under these circumstances it is advisable to use one or more storage batteries seems to me a very difficult question to answer, and most probably will have to be decided on the merits of each individual case.

Mr. Taylor. Mr. A. M. Taylor (*in reply*): I will deal with the speakers as far as possible in the order of their communications.

Replying to Mr. Chappell, I would say that the cost of running lines in this country dealing with heavy powers would probably be much greater than in the United States, as the Post Office would probably take exception to large amounts of power in a single circuit; and to run several circuits or one line of towers would be as costly as my estimate indicated. With regard to the five systems alluded to in the United States, I am not satisfied that these are operating under the conditions postulated in my Fig. 4, my recollection being that the only systems so operating are those in which batteries are used as "buffer batteries," to absorb the momentary variations in power. It would be interesting to hear the views of the firms who put down these installations as to whether they are successful or not; and, if unsuccessful, to know why they failed. In reply to Mr. Kemp, it is quite true that my estimate of the minimum cost of current is based on the conditions stated by him; but, on the other hand, the mere running of the same amount of plant for longer hours would sufficiently extend the limit to which he alludes to enable the additional load of about 50 per cent. contemplated for a steam station to be taken up by the battery, the total kilowatt capacity of plant now run not being in this case exceeded, and under these conditions the cost would be very little in excess of that estimated for the most favourable conditions. In mentioning an *addition* to the existing station load of 50 per cent., to be taken up by the cells, it will be understood that this is the same thing as stating that it would pay to take up 33 per cent. of the *existing* station load by the cells.

In reply to Mr. Forrest, I think it must be agreed that if the supply were, for example, being distributed over a large town, it would be very much better, in the case of a breakdown in the long-distance line, to have two or three hours in which to notify consumers of the impending stoppage, than to spring it upon them unawares. It may be mentioned that, as regards the breaking of an overhead line, complete immunity from interruption of supply could not be secured (where there was no storage) by having two circuits, unless these were carried on two separate lines of towers, at such a distance apart as to secure absolute safety from the back lash of a breaking wire. As regards the deadening of the line at certain times of the day for repairs, I would point out that there is a day and a half at the end of every week available for charge, of which I have not taken account in my Fig. 4. As regards the efficiency of the accumulator sub-station, Mr. Forrest is no doubt aware that my proposals would not involve any greater percentage of losses in line or plant at the time of peak load than obtains under the ordinary methods not employing batteries. The extra units required to compensate for losses in batteries and in charging plant are merely made up for by running the generating plant for longer periods than it would otherwise be run. Mr. Forrest's statement would convey an impression as to inefficiency which is really not the case. In reply to Mr. Groves, the battery which I am proposing would be of quite abnormal dimensions, and would be capable of taking the whole output of the system for short periods without injury. I do not think it would pay any supply authority to have 100 per cent. of its copper standing idle, which is what I understand Mr. Groves to suggest. He is probably speaking from the point of view of distribution in a large town, which is somewhat different from the case of distribution by power companies. I do not advocate the battery as a standby against broken-down underground mains, except under special circumstances. Mr.

In reply to Mr. Boulton, I cannot agree that the cost of energy put into the battery is nearer to 0·2d. per unit than 0·1d. I should be prepared to admit that in certain cases it was nearer to 0·15d. than to 0·1d. As regards the other point raised, the losses incidental to the use of batteries are not, on a water-power scheme, at all so serious as Mr. Boulton and one or two speakers seem to imagine. In any case no larger plant is required at the sending end. In reply to Mr. Rosher, the figure of 25 per cent. has, I agree, been taken too high, and 20 per cent. is probably nearer the mark. My figure was, however, intended to cover not only the copper, but the cost of insulators, towers, etc., and I added something to cover cost of way leaves, which may sometimes be a heavy item.

Dr. Kapp's remarks as regards the Kubel water-power plant are very interesting; but the data in Table A of page 428 of my paper were given as alluding to falls in which the heads were only of a few feet in amount, and I cannot help thinking that perhaps there are two separate installations of water power at the Kubel works, and that Dr. Kapp is alluding to the one and I to the other. His remarks on the storage of water are also very interesting, and in cases where sufficient water is to be found at the receiving end of the line, and where a

Mr. Taylor. natural receptacle can be found at a suitable level, the method he advocates is no doubt superior to electrical storage. Mr. Addenbrooke's and Mr. Orsettich's remarks I have already dealt with somewhat fully in letters to the technical press, and do not propose to deal with them further here.* In conclusion, I greatly regret that I cannot, through pressure of other work, take up here the question of the saving in fixed charges introduced by the use of storage; but I shall hope to deal separately with the subject later on.

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* *Electrical Engineering*, vol. 5, p. 282, 1909. *Electrician*, vol. 62, pp. 929–931 and 975, 1909.